爱因斯坦探针(EP)科学讨论会
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# Probing Black Hole Astrophysics with X-Ray Nuclear Transients: TDEs, QPEs and Changing-Look AGNs

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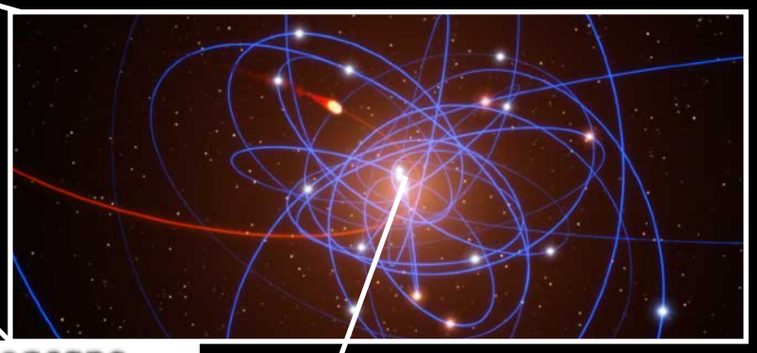
# What can we learn from the X-ray nuclear transients?

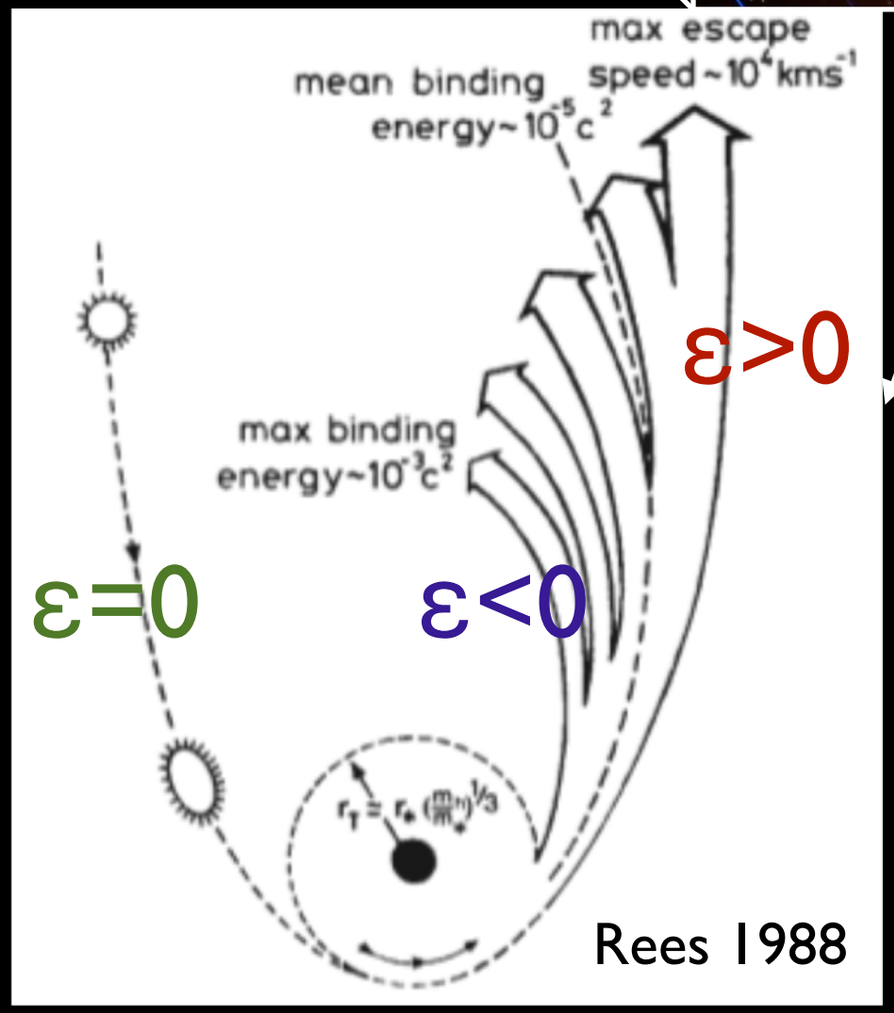
- Tidal disruption events
- Quasi-periodic eruptions
- Changing-look AGNs

# Tidal Disruption Events

10-100 kpc

1 parsec

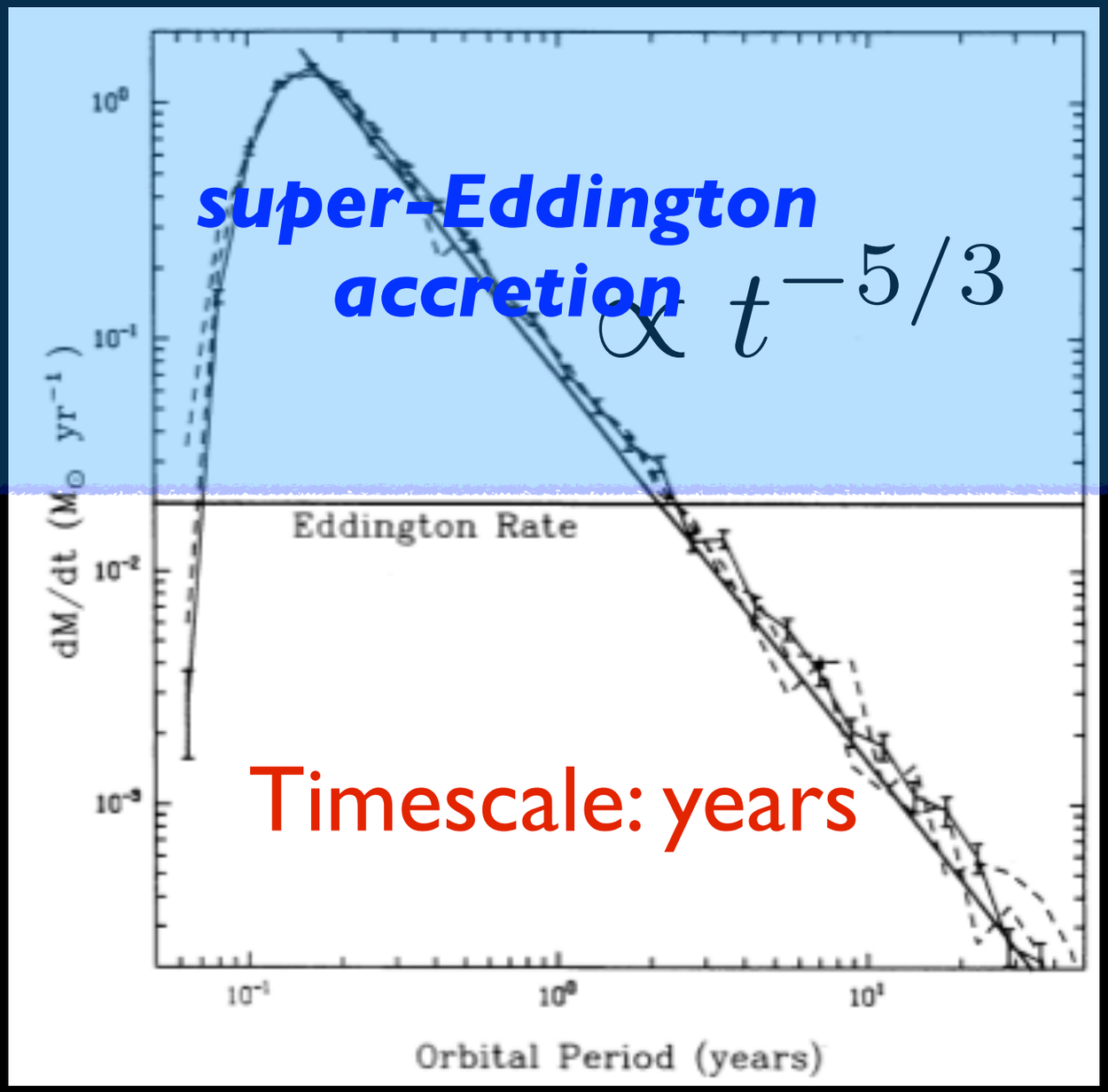


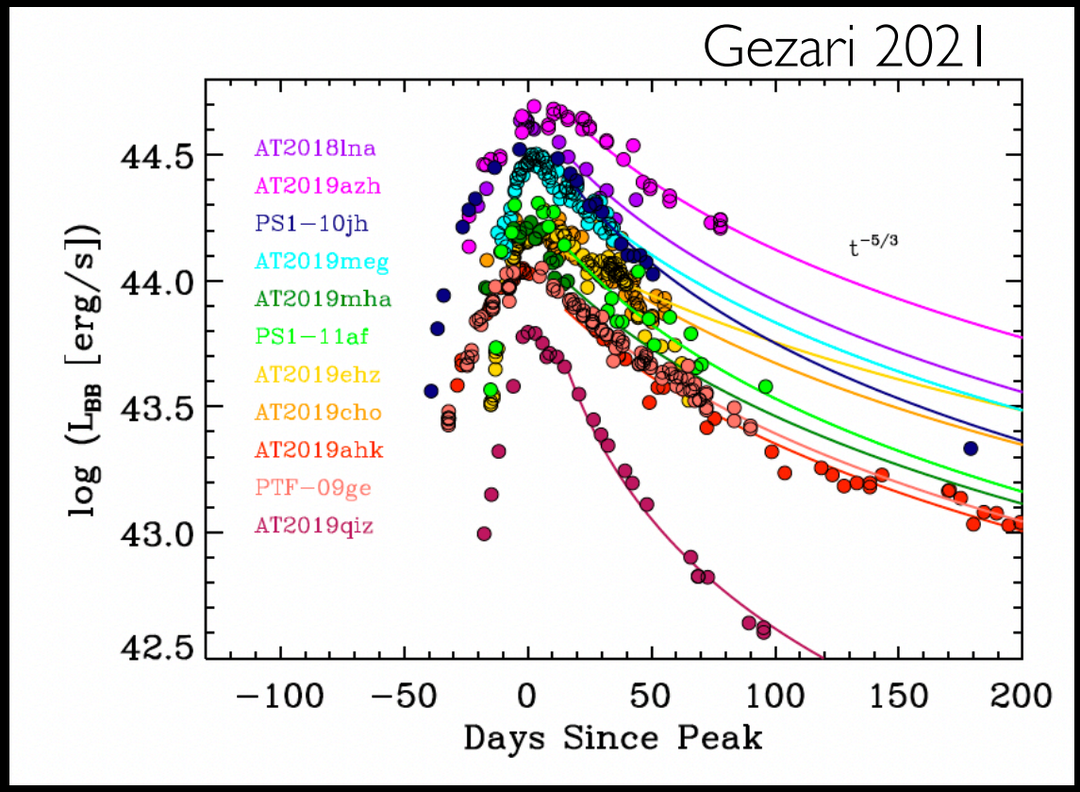



Rees 1988

MBH tidal force > stellar self-gravity

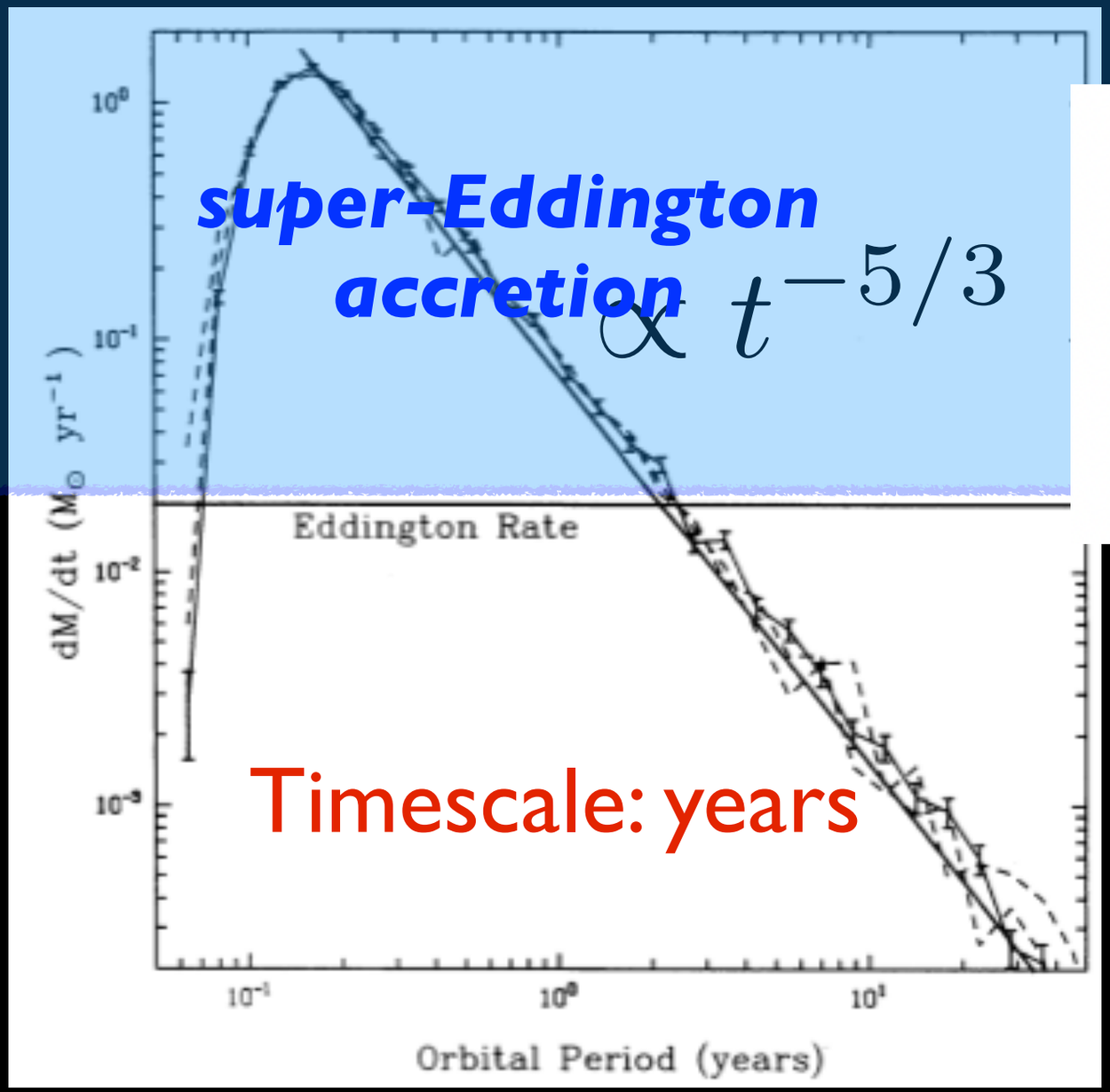
# Debris Fallback Rate




Evans & Kochanek 1989; Phinney 1989; Lodato et al. 2009; Guillochon & Ramirez-Ruiz 2013; Tejeda et al. 2017; Golightly et al. 2019; Gafton & Rosswog 2019; Ryu et al. 2020

# Debris Fallback Rate




$$\dot{M} = \frac{\mathrm{d}M}{\mathrm{d}t} = \frac{\mathrm{d}M}{\mathrm{d}E}\frac{\mathrm{d}E}{\mathrm{d}t} = \frac{M_\star}{3t_{\rm min}}\left(\frac{t}{t_{\rm min}}\right)^{-5/3},$$

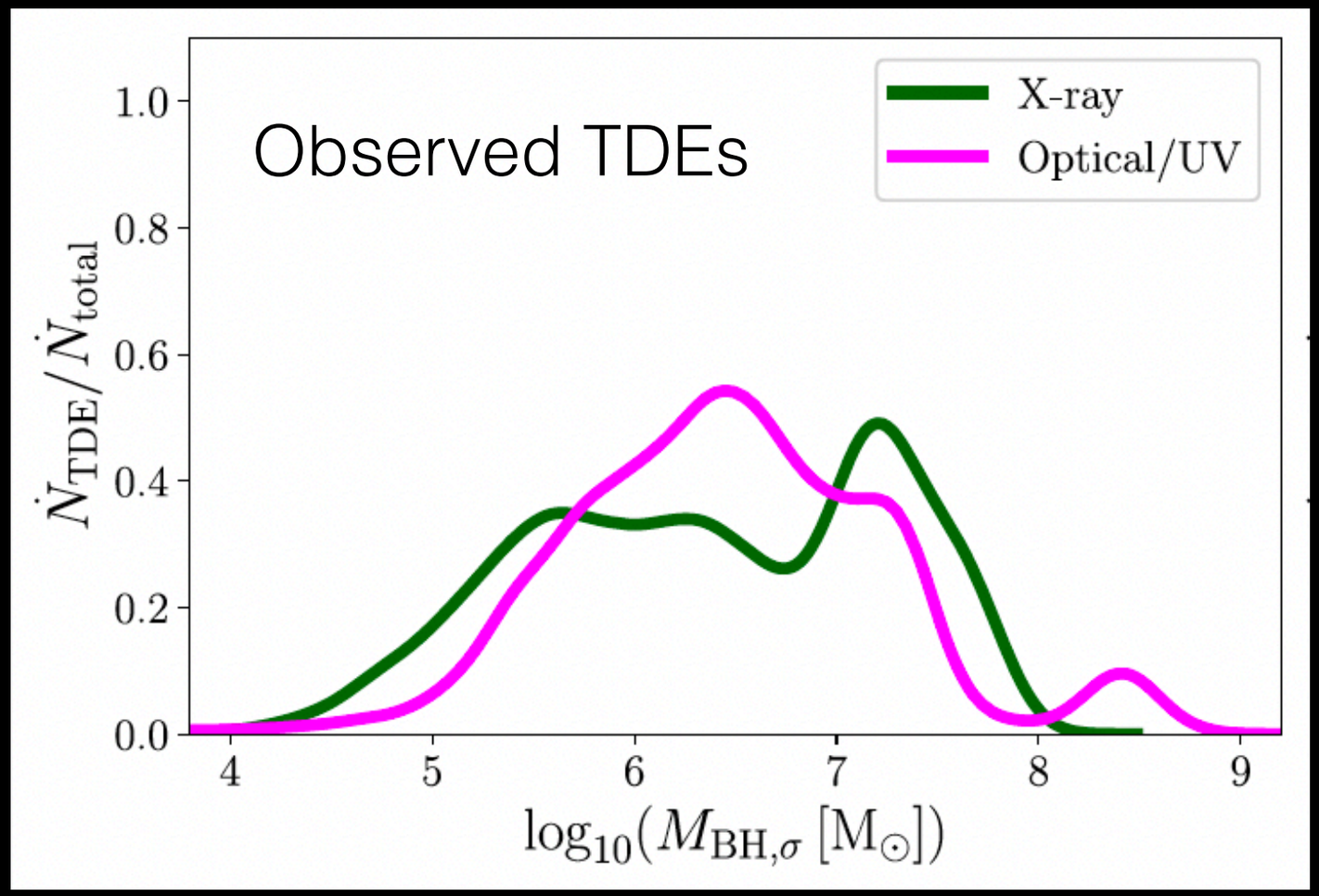
$$t_{\rm min} = \frac{\pi}{\sqrt{2}}\left(\frac{R_\star^3}{GM_\star}\right)^{1/2}\left(\frac{M_{\rm BH}}{M_\star}\right)^{1/2}$$

$$\approx 40\,\mathrm{days}\left(\frac{M_{\rm BH}}{10^6 M_\odot}\right)^{1/2}\left(\frac{M_\star}{M_\odot}\right)^{-1}\left(\frac{R_\star}{R_\odot}\right)^{3/2}.$$

Evolution timescale depends on $M_{BH}$

Evans & Kochanek 1989; Phinney 1989; Lodato et al. 2009; Guillochon & Ramirez-Ruiz 2013; Tejeda et al. 2017; Golightly et al. 2019; Gafton & Rosswog 2019; Ryu et al. 2020

- ⋆ Constrain the population of dormant supermassive black holes

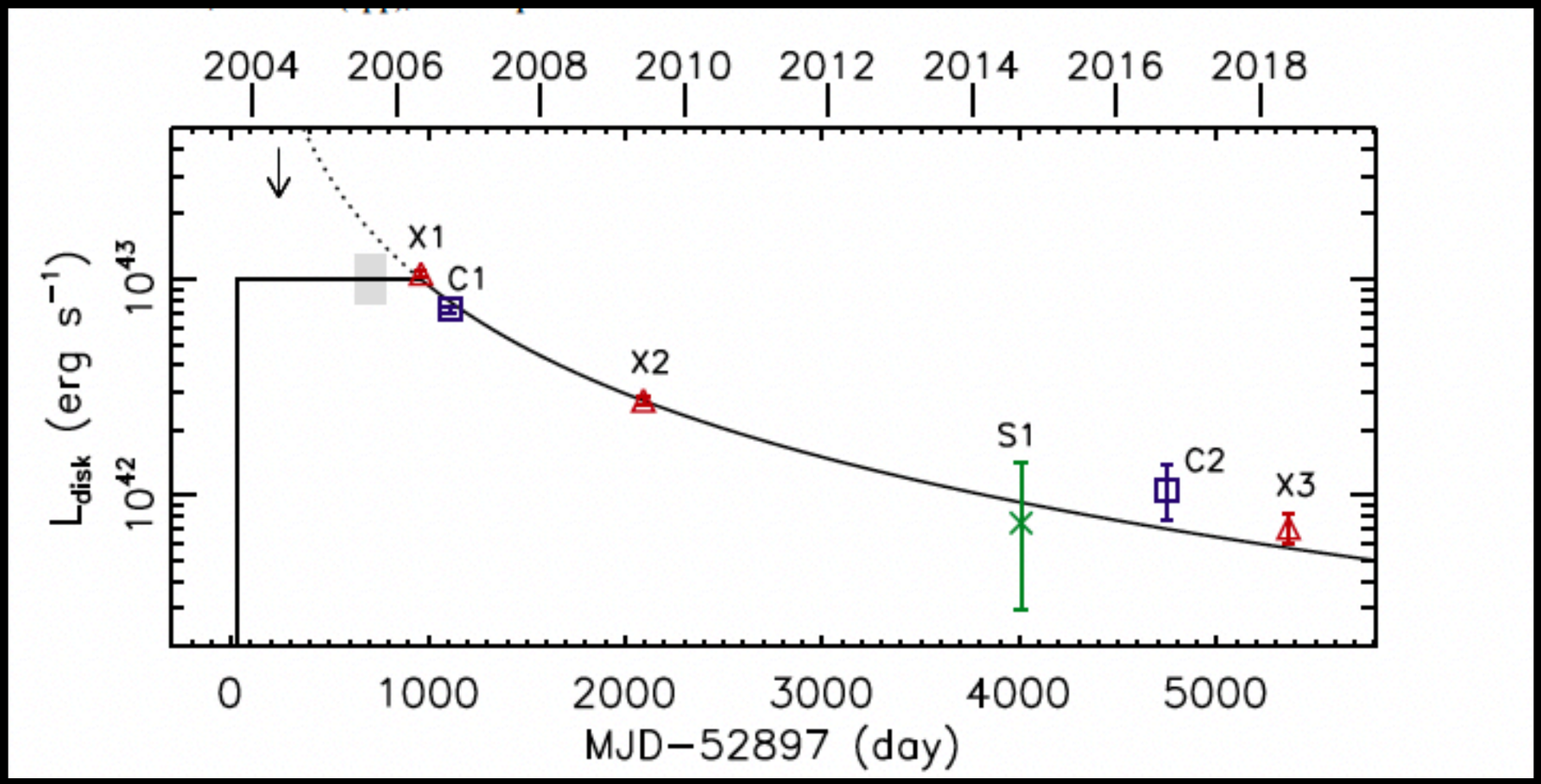



- Only 11 X-ray TDE with accurate $M_{BH}$ estimates
- 22 optical TDE with accurate $M_{BH}$ estimates

Wong, Pfister, **LD**, 2022

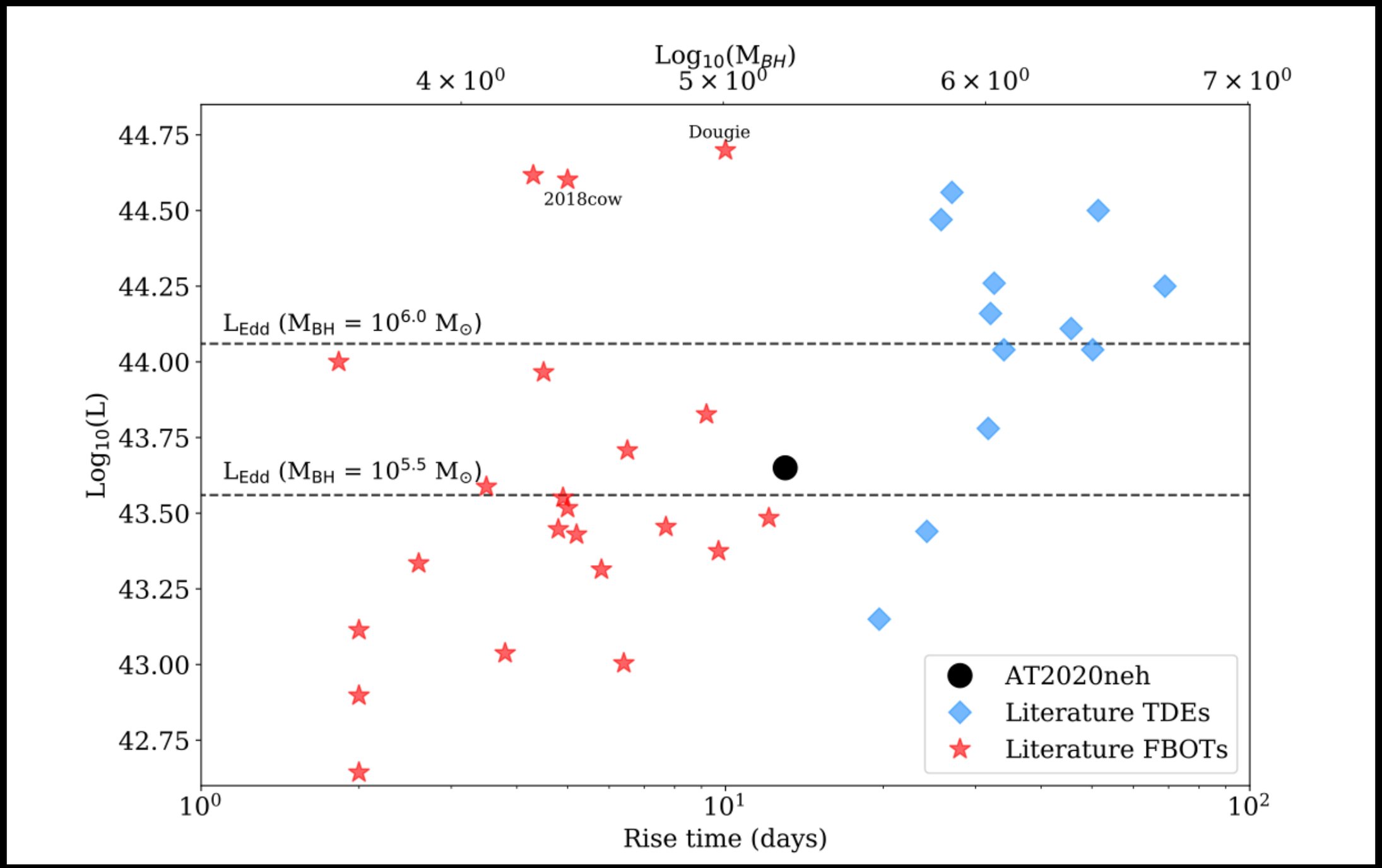
- Detect intermediate-mass black holes

X-ray TDE around $10^5$ $M_\odot$ IMBH?

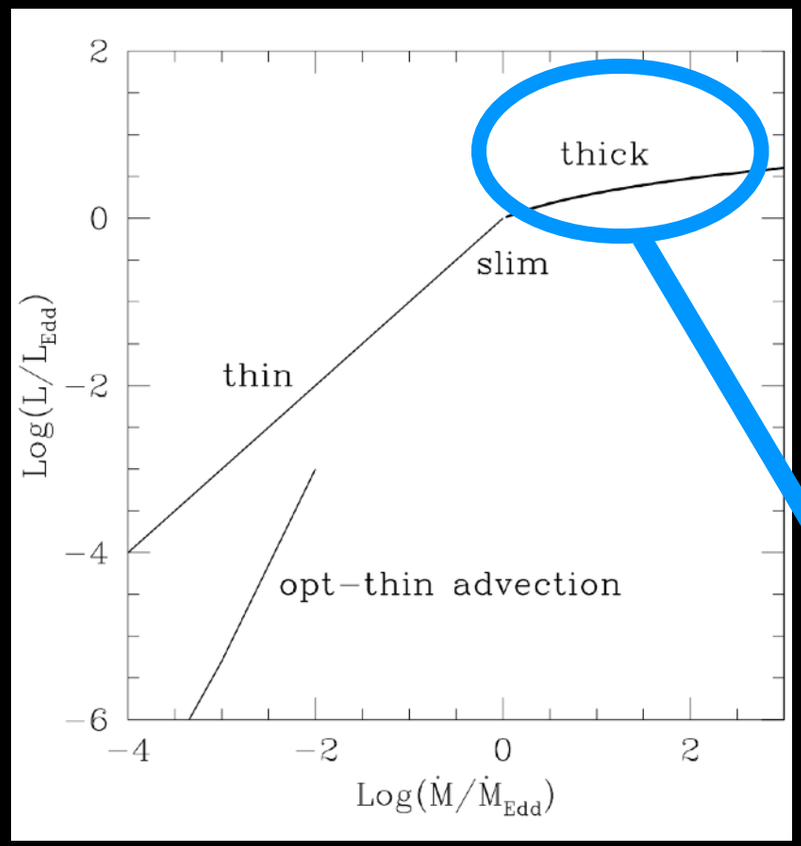



Lin et al. 2018, 2020

- ★ Detect intermediate-mass black holes




Angus et al. 2022



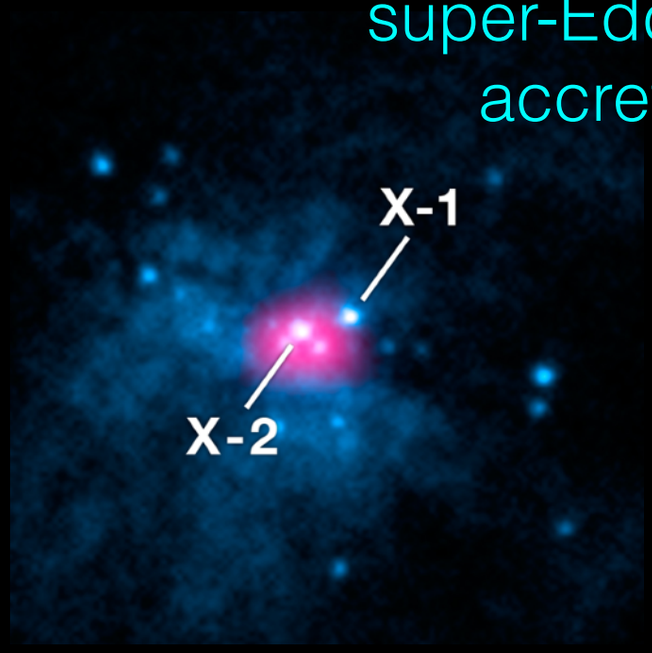

Ulmer 1999

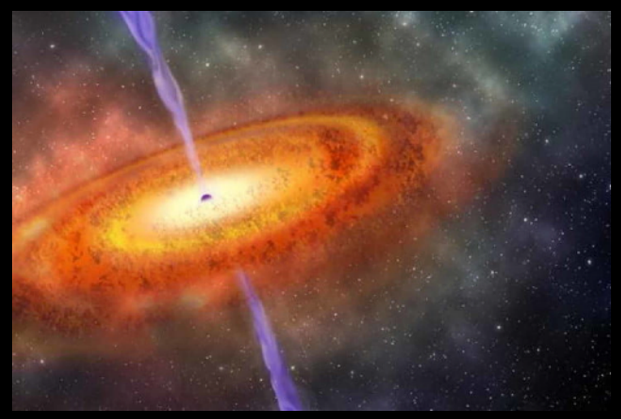
★Study (super-Eddington) black hole accretion & outflow physics

See review by **LD**, Lodato & Cheng, Space Science Reviews, 2022

super-Eddington accretion

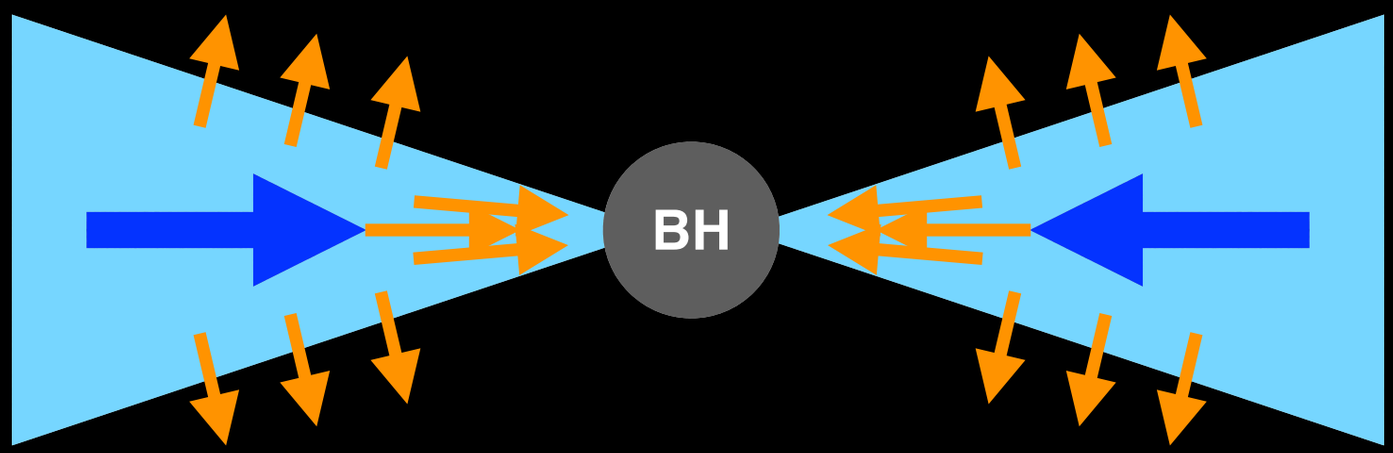
Ultra luminous X-ray sources (ULXs)



High-redshift quasars

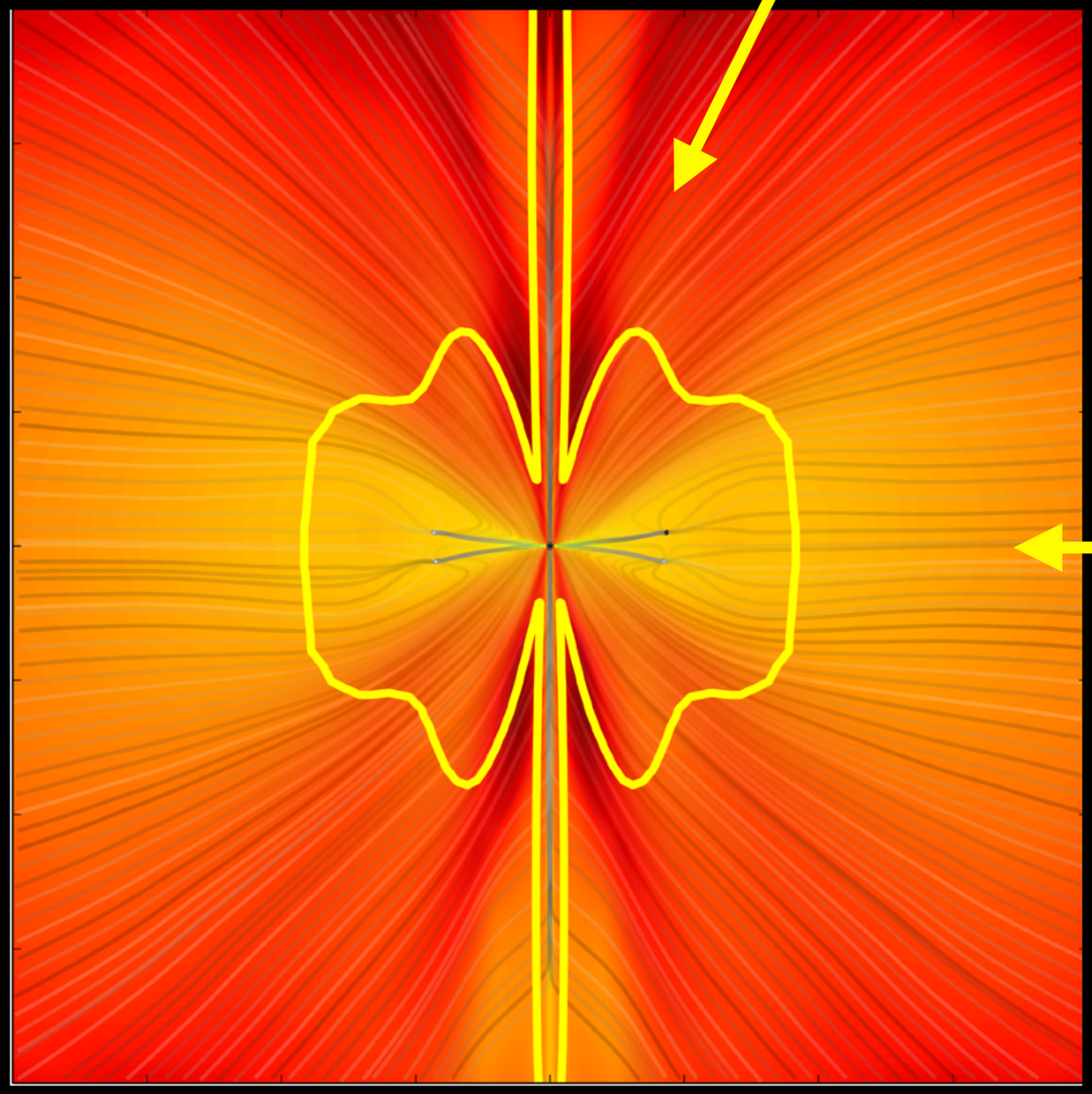
# Super-Eddington Accretion




- Large radiation pressure
- Geometrically thick disk, radiation-driven winds
- Photons coupled to gas, photon trapping in the inner disk

Shakura & Sunyaev 1973, Begelman 1978,  Abramowicz et al. 1988, Ulmer 1999

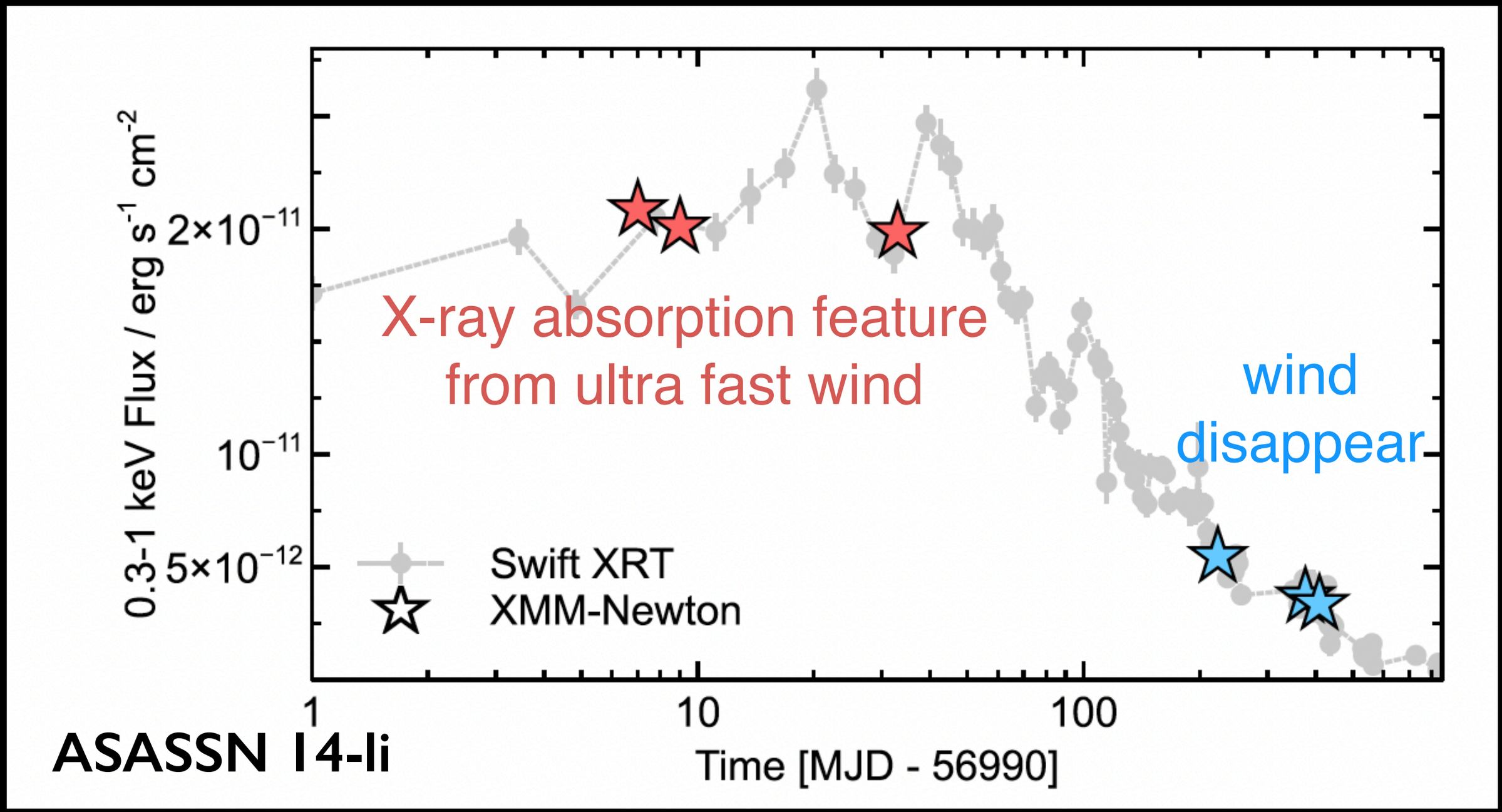
# Super-Eddington Luminosity




LD et al. 2018

# X-ray TDEs Launching Ultra-Fast Wind

wind ↔ accretion

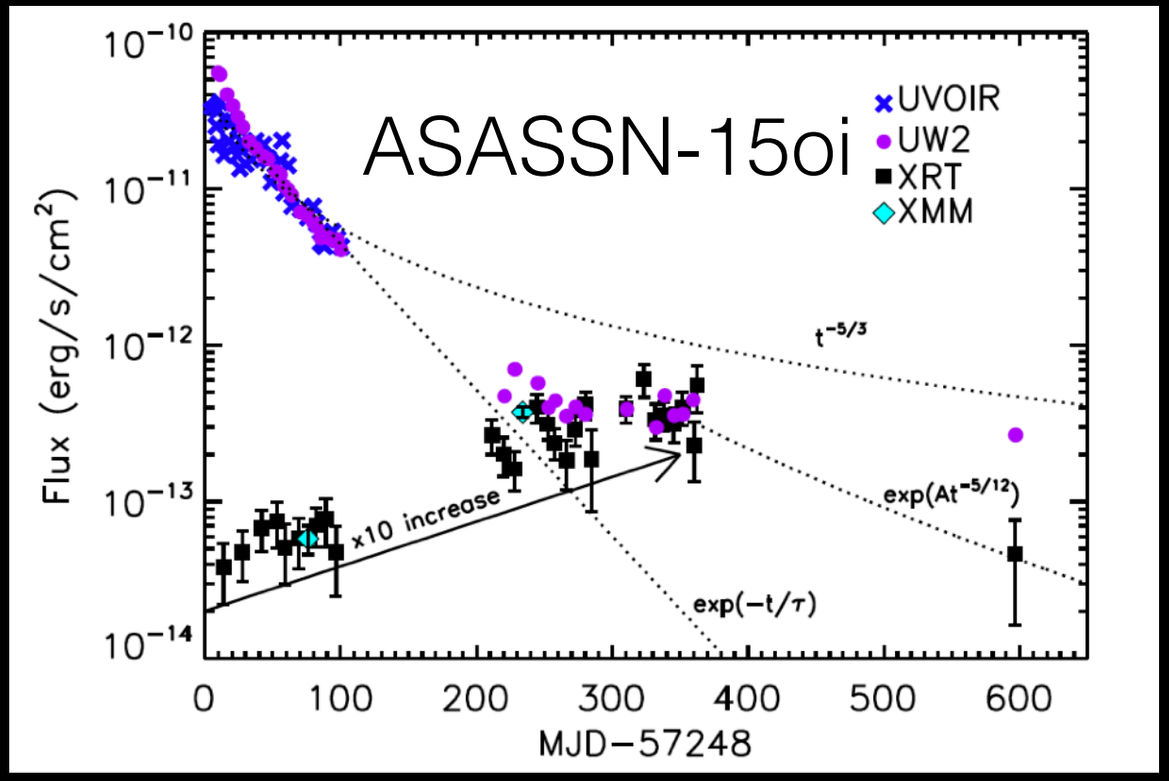





Kara, **LD,** Reynolds et al. 2018

# X-ray vs. Optical TDEs

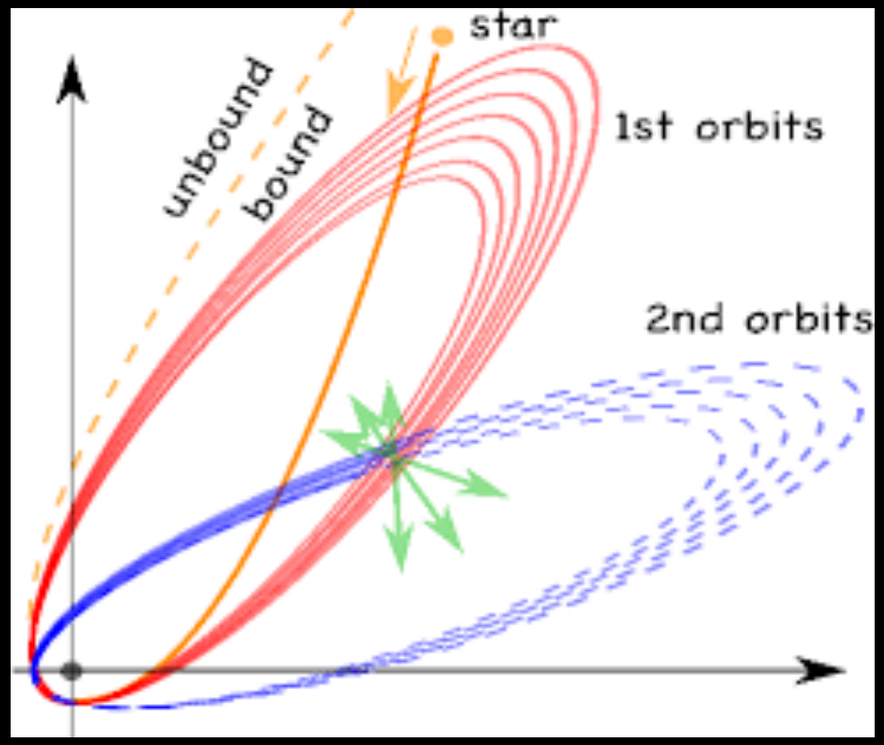
- At Peak: X-ray emissions with $T_{BB} \sim 10^{5\text{-}6}$ K vs. UV/optical emissions at peak with $T_{BB} \sim 10^{4}$ K
- Many optical TDEs rebrighten in X-rays at late time.




Gezari et al. 2017, Holoien et al. 2018, Wevers et al. 2019, Hinkle et al. 2021, Liu et al. 2022

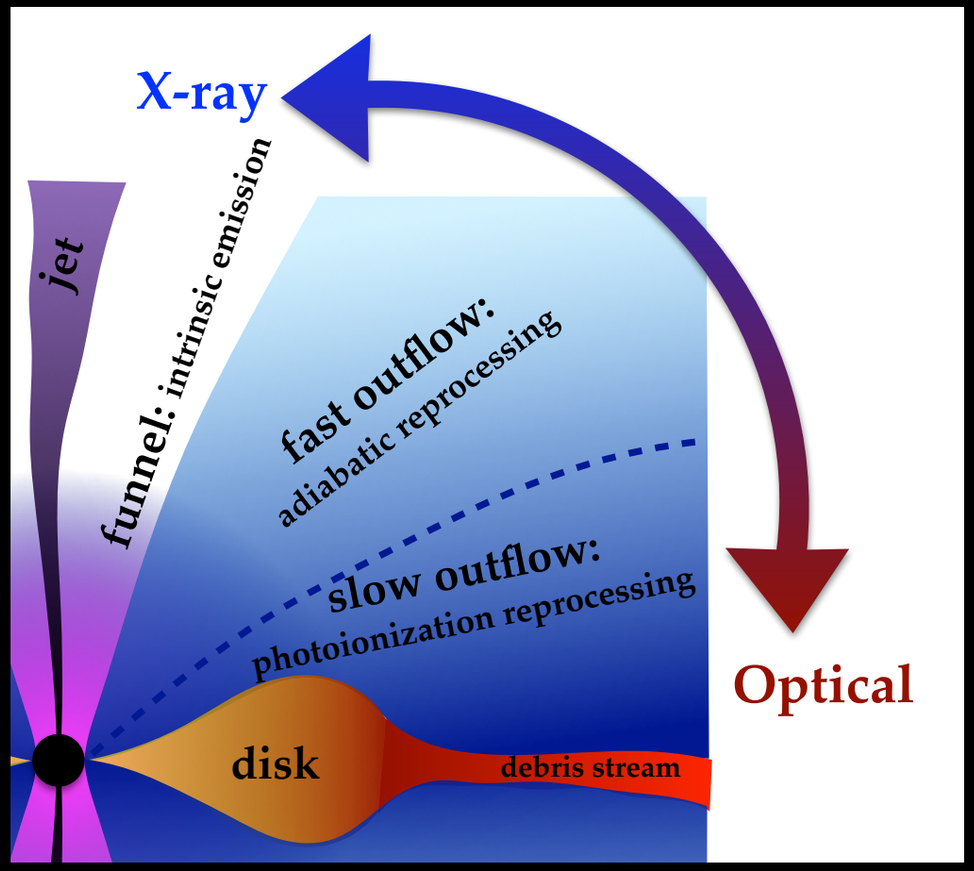
# Optical TDEs: Delayed Accretion vs Reprocessing

- ✦ Optical produced by debris stream shocks
- ✦ Disks forms at later time producing X-rays



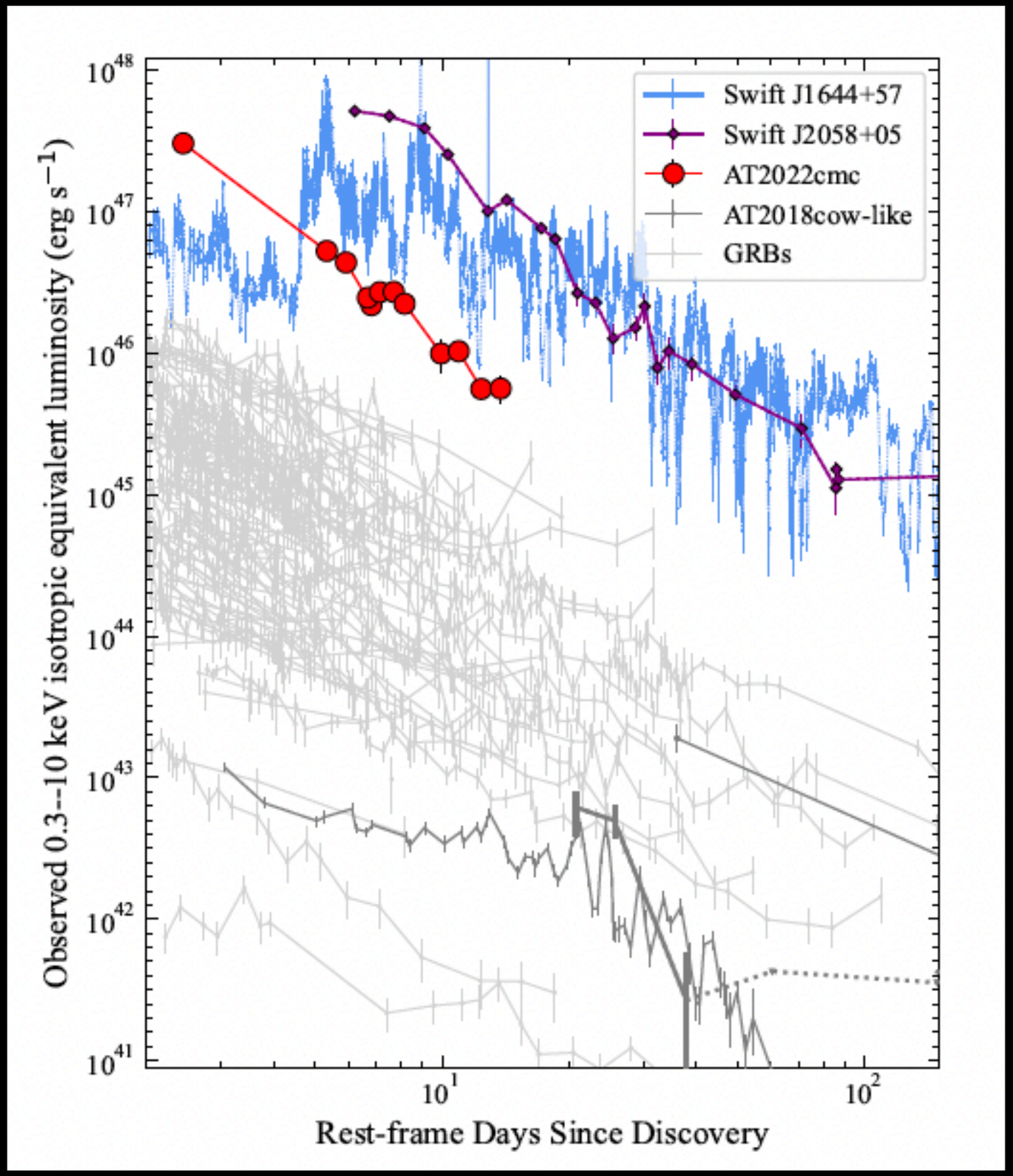

e.g. Piran et al. 2015, Bonnerot et al. 2021

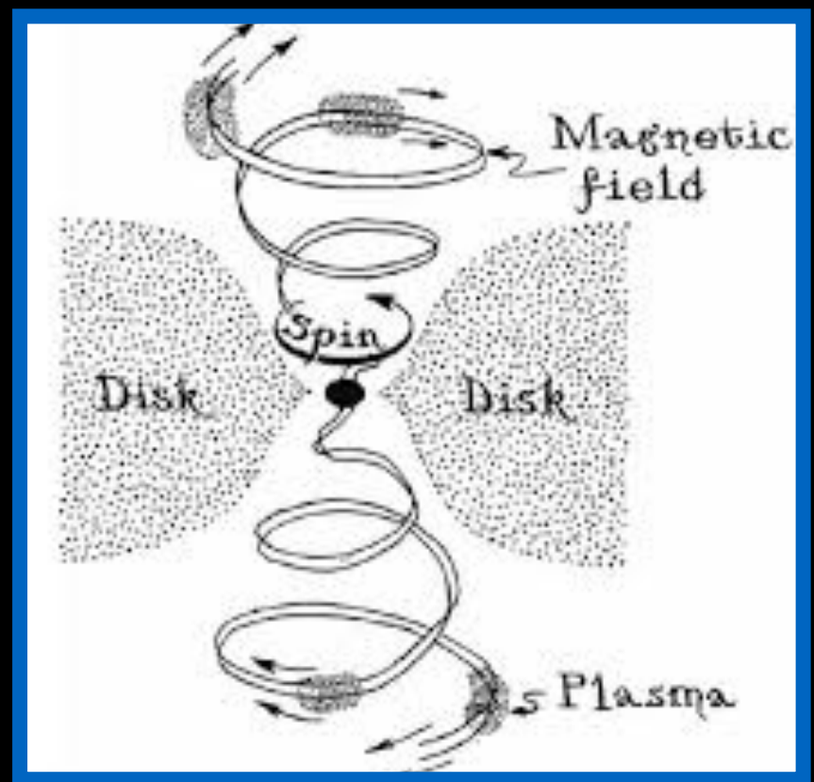
- ✦ Optical emissions are reprocessing X-rays
- ✦ Funnel opens up at late time when X-rays leak out




e.g. LD et al. 2018; Thomsen, LD et al. 2022b

# 4 TDEs Producing Relativist Jets

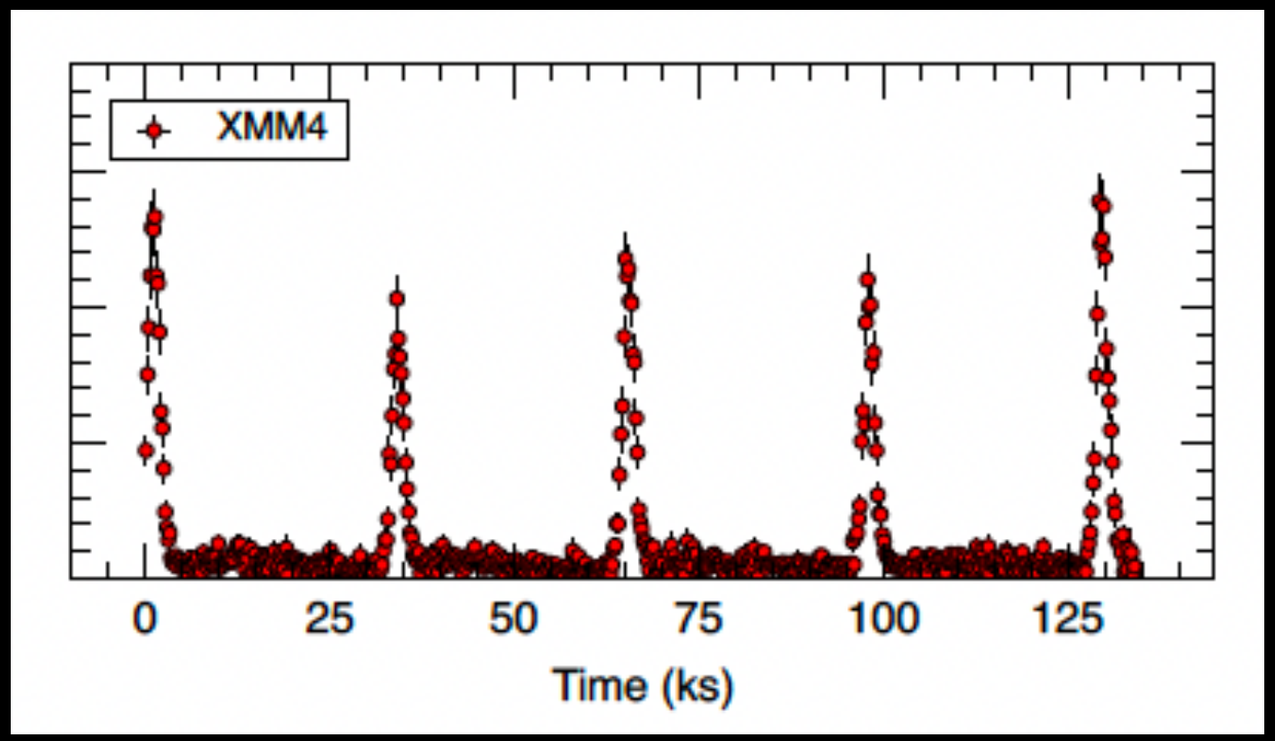



Burrows et al 2011, Bloom et al 2011, Levan et al 2011, Zauderer et al 2011; Cenko et al. 2012; Brown et al. 2015; Andreoni et al. 2022; Pasham et al. 2023

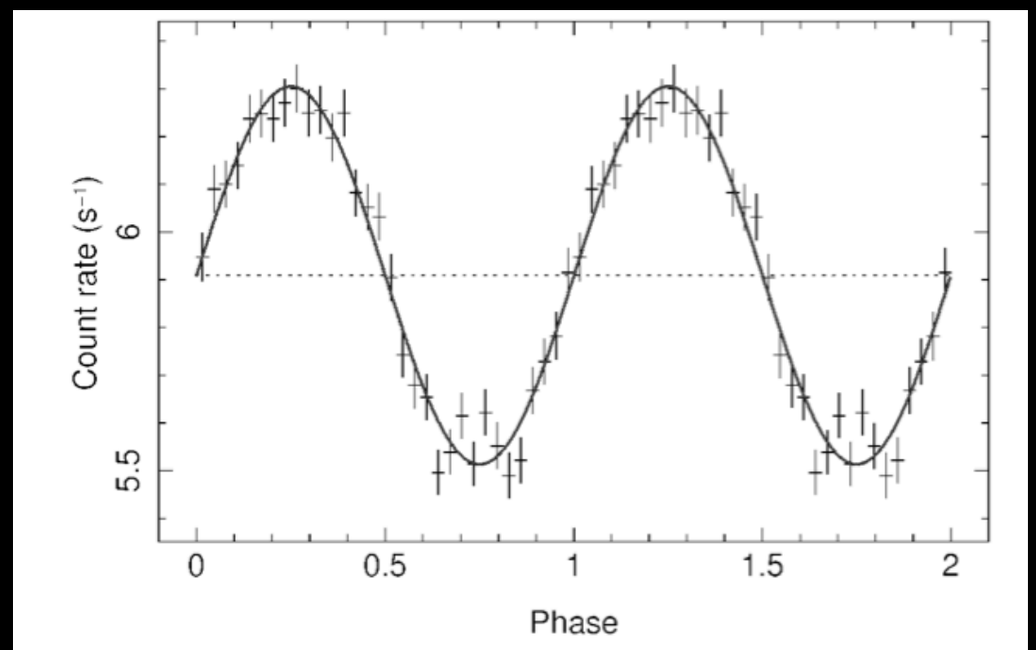
# Quasi-Periodic Eruptions (QPEs)

- QPE:
  GSN 069




Miniutii et al. 2019, 2022

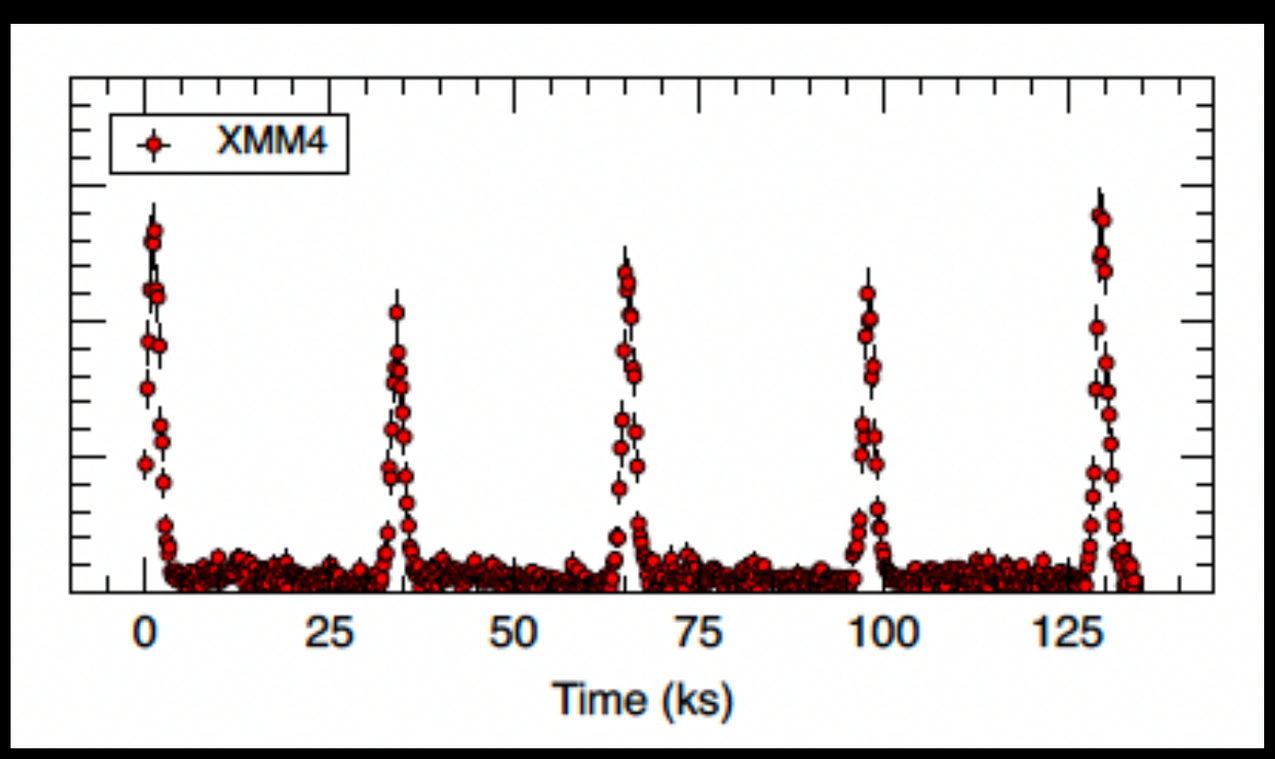
- QPO:
  RE J1034+396

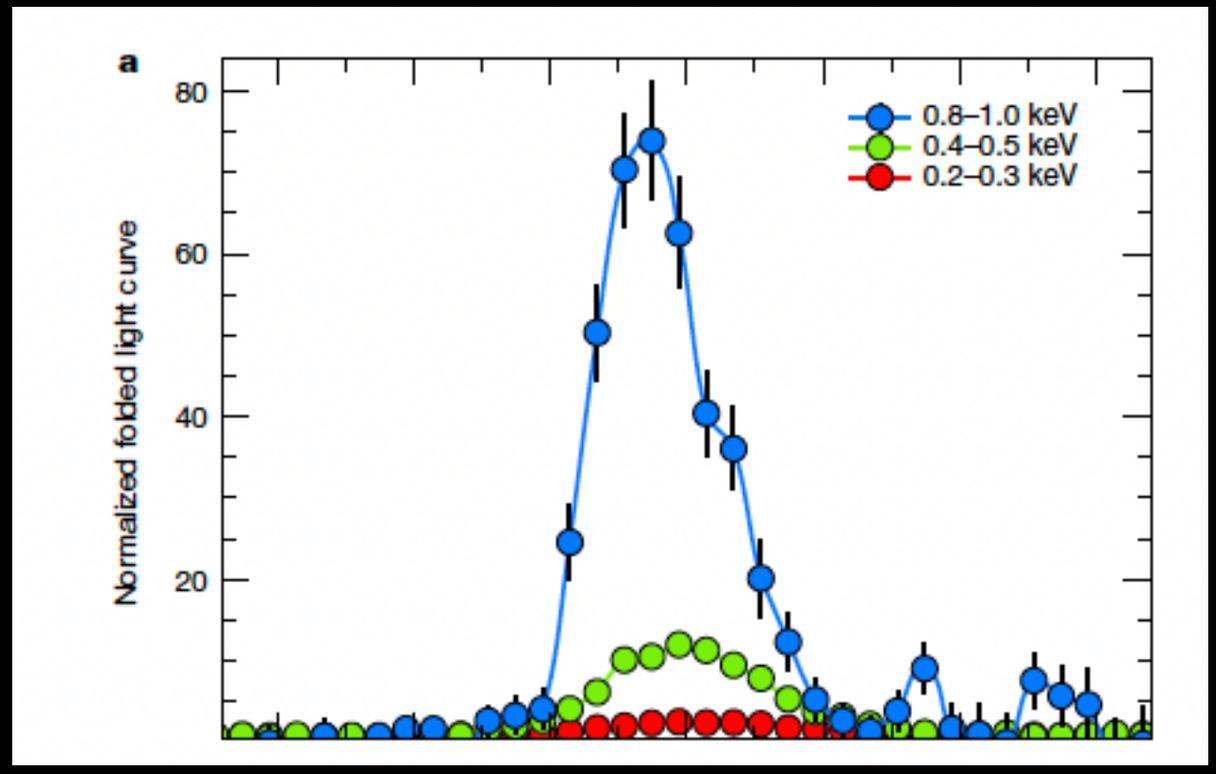



Gierlinski et al. 2008

# QPE GSN 069

- High amplitude X-ray flares, ~$10^{42}$ erg $s^{-1}$
- Recurring every 9 hrs
- Very soft spectrum
- Small host black hole mass ~ $10^{5\text{-}6}$ $M_\odot$




Miniutii et al. 2019, 2022

# QPE Population

- **GSN 069** (Miniutti et al. 2019, 2022) — QPE following a X-ray TDE
- **RX J1301.9+2747** (Giustini et al. 2020)
- **eRO-QPE1**(Arcodia et al. 2021)
- **eRO-QPE2** (Arcodia et al. 2021)
- **XMMSL1 J024916.6-041244** (Chakraborty et al. 2021) — QPE following a X-ray TDE
- **Tormund** / **AT 2019vcb** (Quintin et al. 2023) - QPE following an optical TDE

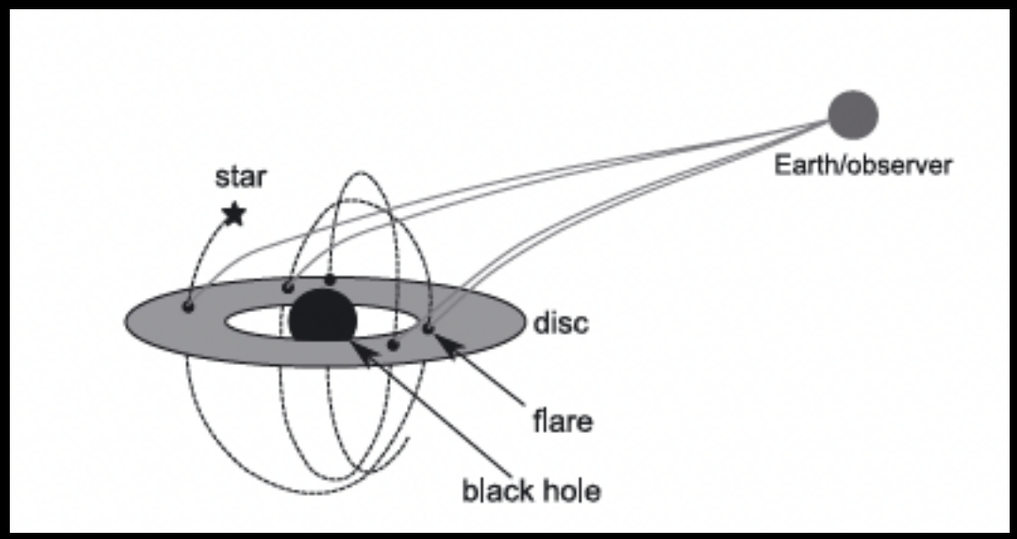
# QPE Models

- ✦ Accretion disk instabilities (e.g. Pan et al. 2022)
- ✦ Tidal stripping of a star (e.g. King 2020; Zhao et al. 2022; Linial & Sari 2022; Wang et al. 2022; Chen et al. 2023)
- ✦ Collision between an orbiting object and an accretion disk (Xian et al. 2021; Linial & Metzger 2023)

Collision pattern ↔ precession rates

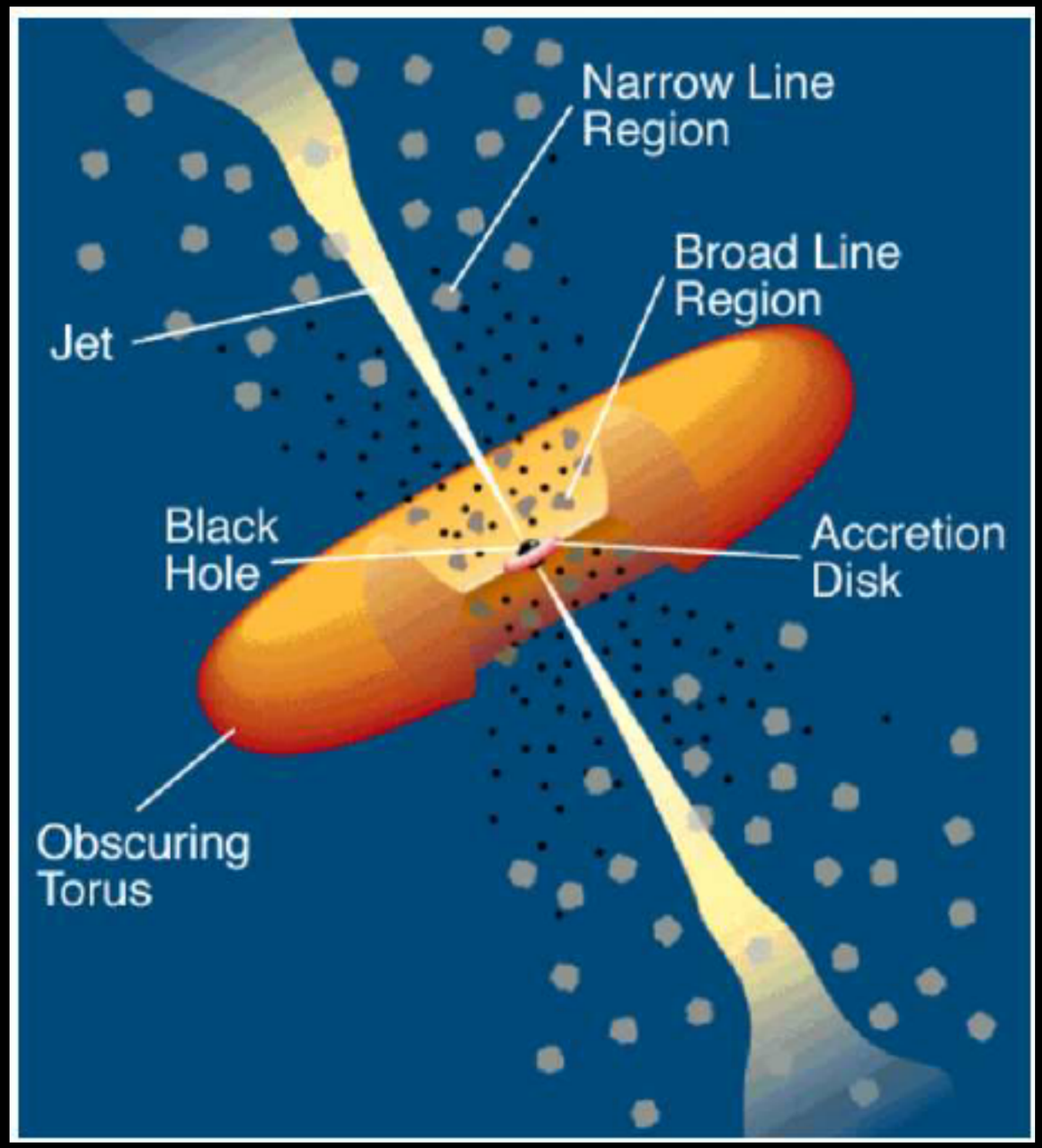
set by black hole mass and spin

LD et al. 2010



# Classical AGN Unification

**Type I AGN**
**(Unobscured)**

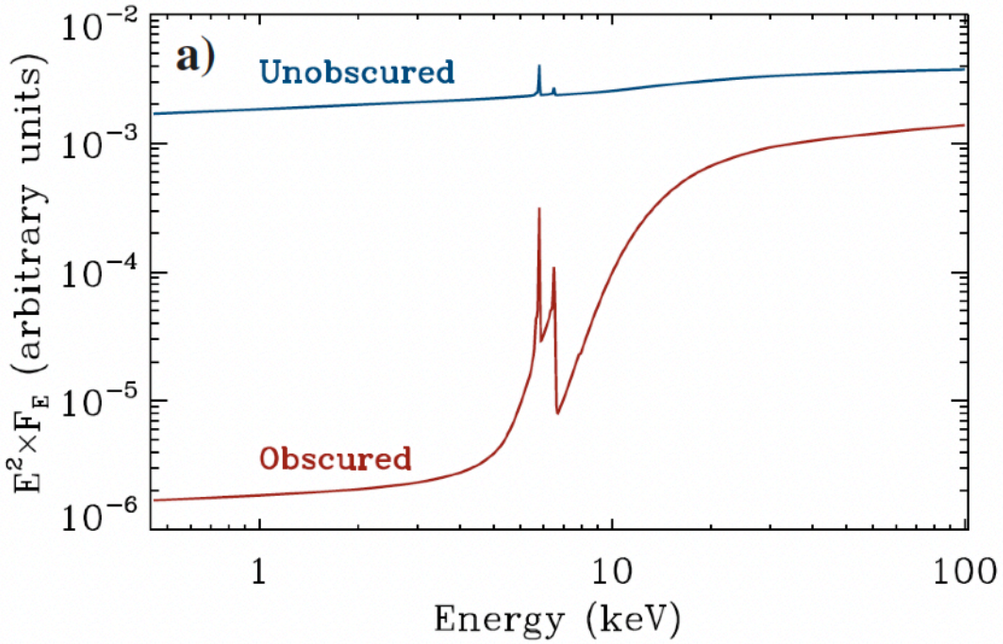



**Type II AGN**
**(Obscured)**

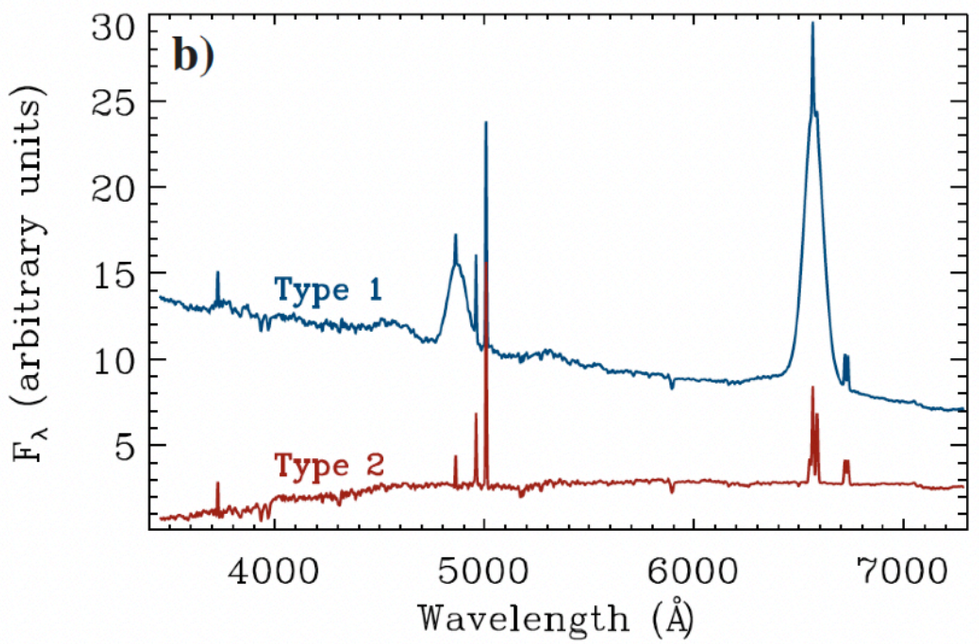
# Changing-Look AGNs: AGNs exhibiting changes in column density (X-ray) or continuum/broad lines (optical/UV)

*Spectral classes identified in:*

**X-rays**




**UV/optical**

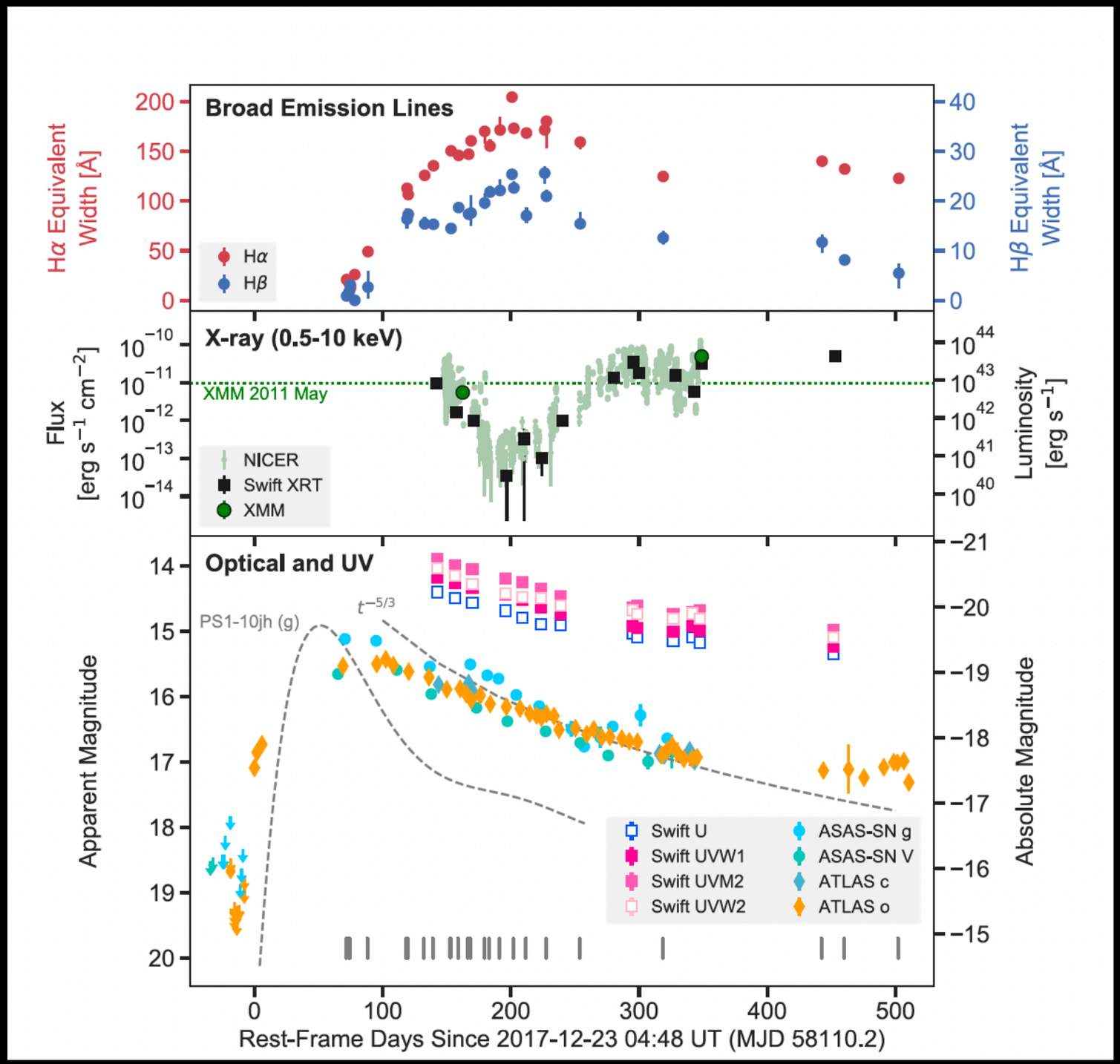



*Spectral transitions usually driven by:*

**Changing obscuration (CO-AGN)** **Changing accretion state (CS-AGN)**

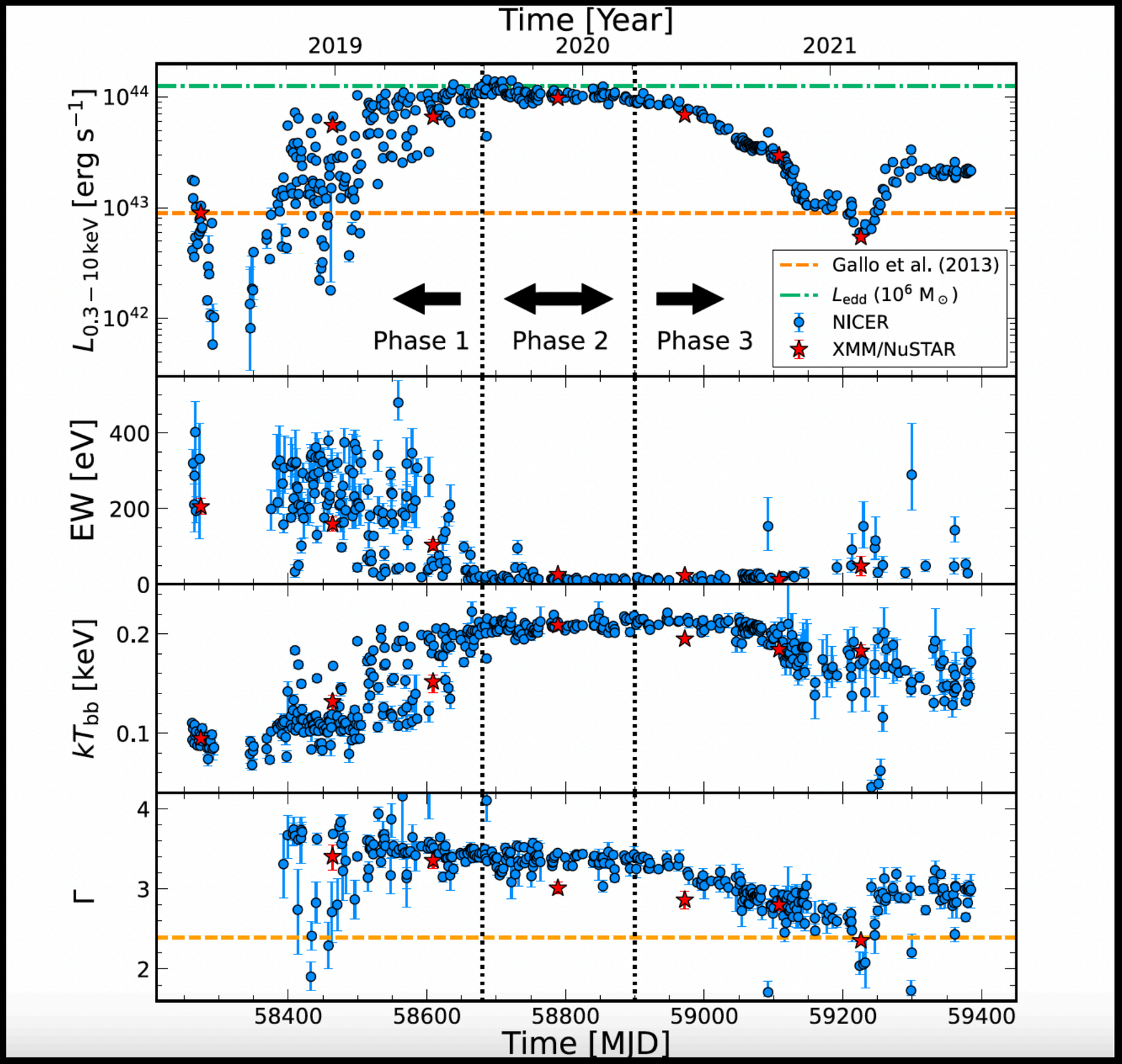
Review by Ricci & Trakhtenbrot 2022

# The Peculiar Case of 1ES 1927+654




Trakhtenbrot et al. 2019; Ricci et al. 2020, 2021; Masterson et al. 2022; Laha et al. 2022; Li et al. 2022

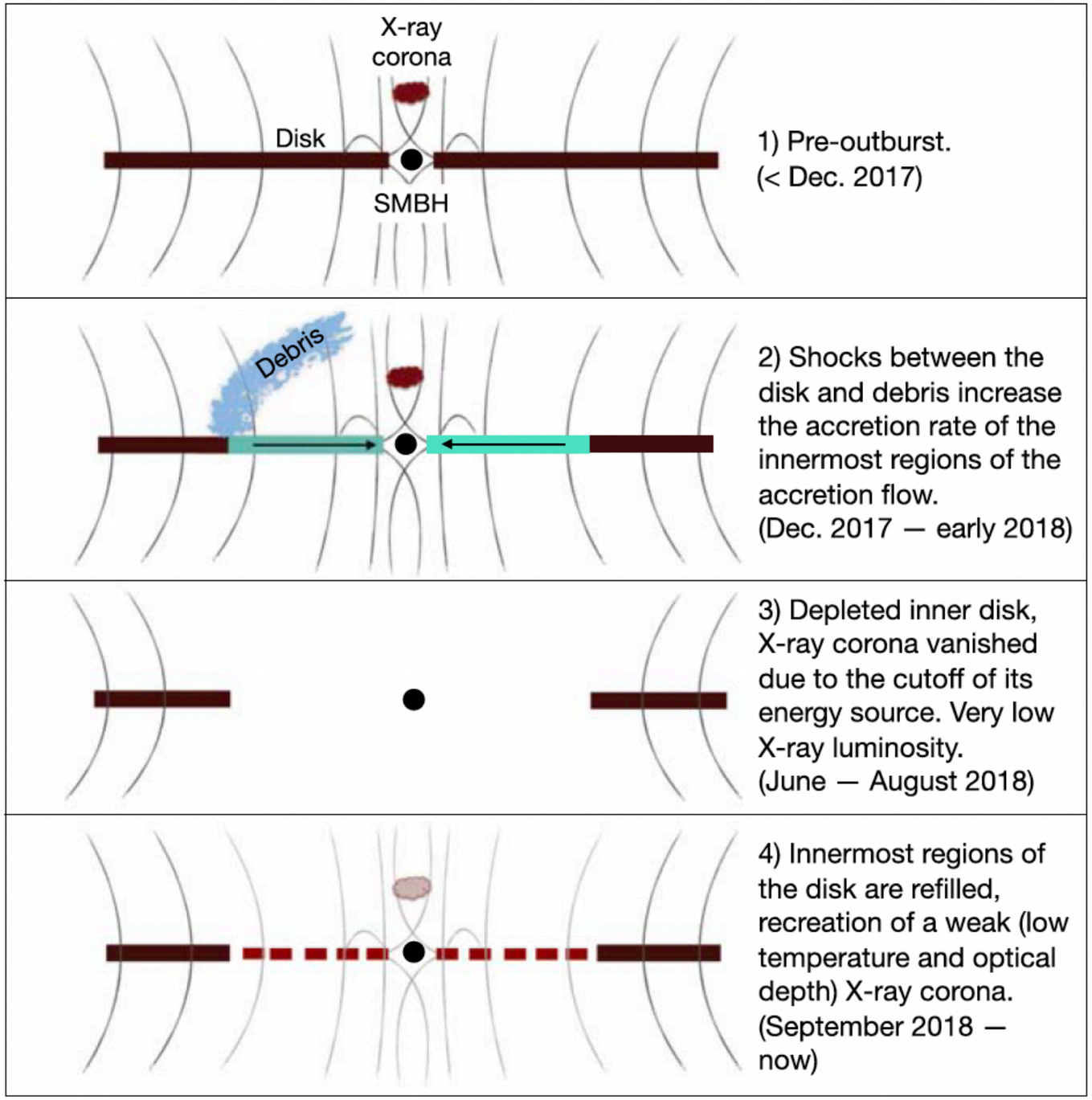
# The Peculiar Case of 1ES 1927+654




- Formation of the corona
- Super-Eddington luminosity?

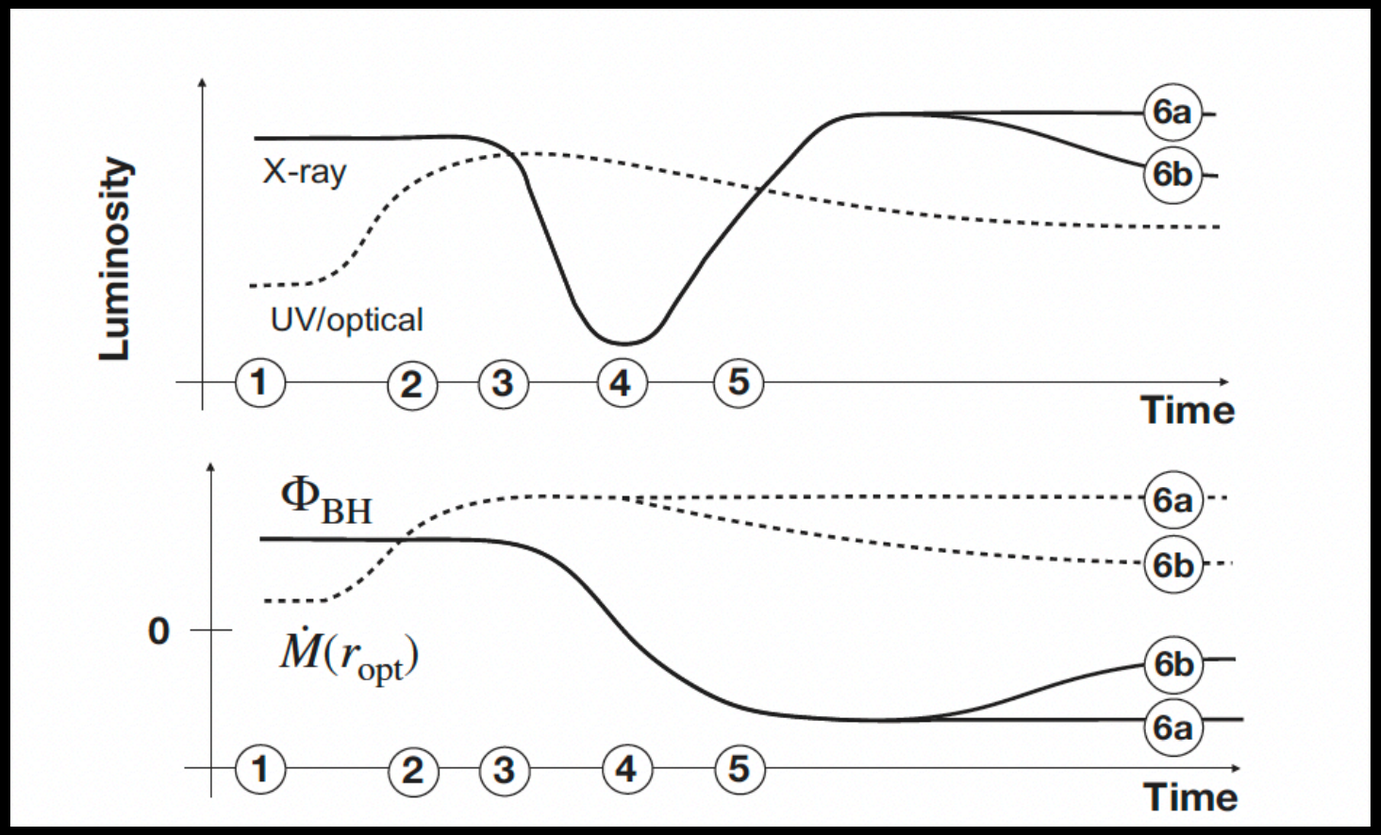
Masterson et al. 2022
Li et al. 2022

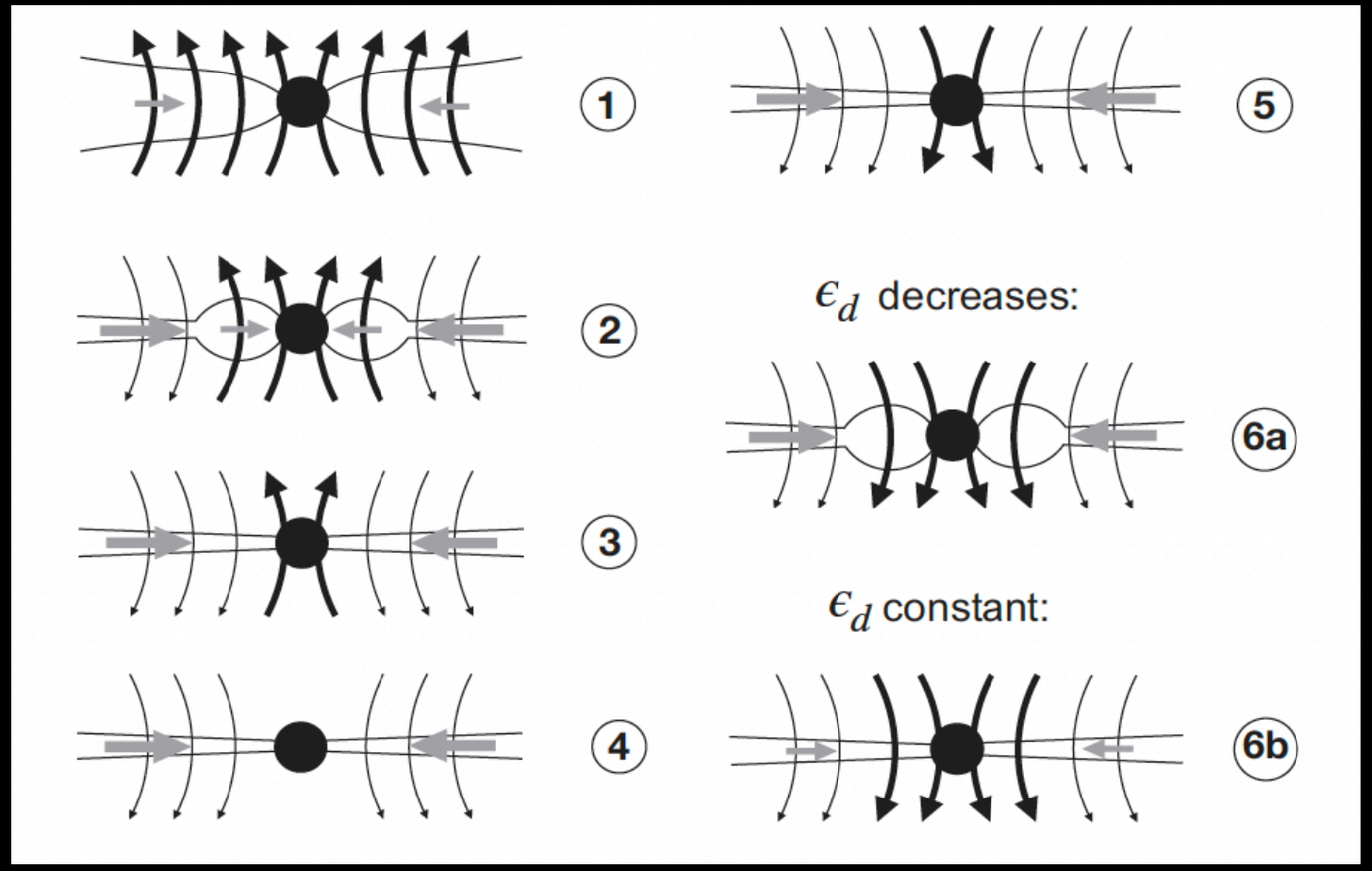
# The Peculiar Case of 1ES 1927+654




- ✦ TDE in a pre-existing AGN?

Ricci et al. 2020




# The Peculiar Case of 1ES 1927+654

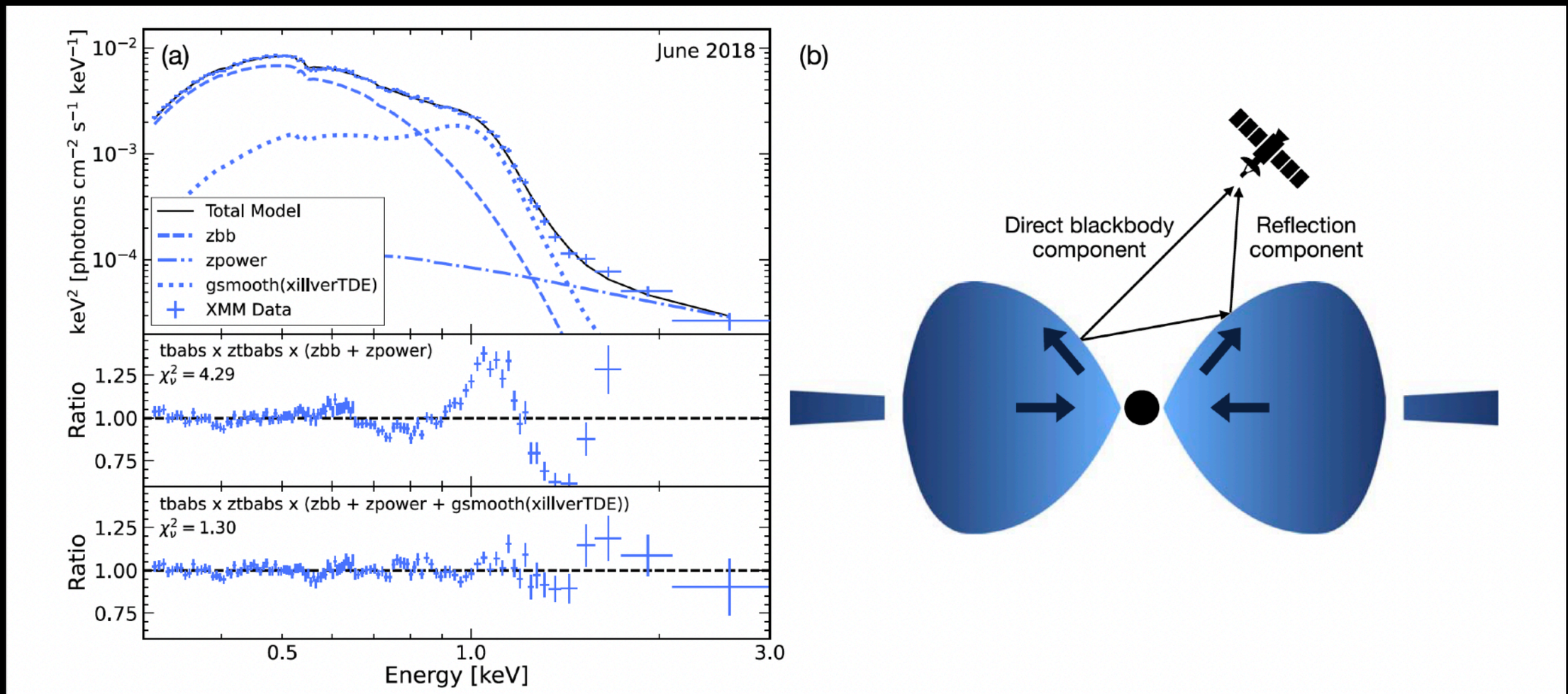
- Inversion of disk magnetic flux?

Scepi et al. 2021

# The Peculiar Case of 1ES 1927+654

- X-ray continuum and 1 keV line modelled using X-ray reverberation from super-Eddington outflow
- Line profile: symmetric and blueshifted

(Thomsen, **LD**, et al. 2019, 2022a)




Masterson et al. 2022

# Summary

Various types of X-ray nuclear transients have been detected, including TDEs, QPEs and changing-look AGNs.

TDEs can allow us to detect SMBHs and IMBHs, and study accretion, wind and jet physics around black holes.

6 QPEs are detected, with a few different types of theoretical models proposed.

Changing-look AGNs might not all be produced by the same mechanism — Some might teach us about corona formation and extreme accretion physics.

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